

The paper describes the retrieval of H<sub>2</sub>O from ground-based solar absorption spectra recorded in the near-infrared spectral region. The spectral region and resolution has been chosen to agree with the TCCON (Total Carbon Column Observing Network) requirements. Since the TCCON measurements, concentrating on the long-lived greenhouse gases CO<sub>2</sub> and CH<sub>4</sub>, are expected to be performed on the longer time-scale, the analysis method presented in this paper gives the opportunity to obtain H<sub>2</sub>O also on long time scales.

MAJOR COMMENT: The article by itself is a demonstration of principle. Why this is certainly interesting in the context of the TCCON network the possibility that H<sub>2</sub>O can be measured using this technique has been demonstrated several times by the same author for other wavelengths, and also in the near infrared spectral region. To me the article is a subset of the three articles by Schneider et al.

1. Schneider, M.; Hase, F. & Blumenstock, T. Water vapour profiles by ground-based FTIR spectroscopy: study for an optimised retrieval and its validation *Atmos. Chem. Phys.*, 2006, 6, 811-830
2. Schneider, M.; Romero, P. M.; Hase, F.; Blumenstock, T.; Cuevas, E. & Ramos, R. Quality assessment of Izaña's upper-air water vapour measurement techniques: FTIR, Cimel, MFRSR, GPS, and Vaisala RS92 *Atmos. Meas. Tech. Discuss.*, 2009, 2, 1625 - 1662.
3. M. Schneider, G. C. Toon, J.-F. Blavier, F. Hase, and T. Leblanc H<sub>2</sub>O and  $\delta$ D profiles remotely-sensed from ground in different spectral infrared regions, *Atmos. Meas. Tech. Discuss.*, 3, 3105-3132, 2010

The only difference in this article is the resolution, which is set to 0.02 cm<sup>-1</sup>, according to the TCCON requirements. The conclusions drawn (broadening of the averaging kernels, slightly lower altitude resolution) are straightforward and to my opinion do not require a separate paper. Therefore I recommend to merge this paper with the one from 2010, which is still under discussion.

We disagree with the referee claiming that the retrieval of H<sub>2</sub>O profiles from TCCON spectra should be a straightforward issue. The lower resolution of the TCCON spectra is an important aspect. Spectroscopic uncertainties (HITRAN parameters, line shape model: e.g. Voigt versus speed dependent Voigt) have very likely different effects on the retrievals depending on the spectral resolution. The same might be true for the temperature profile retrieval. The referee herself/himself mentions in one of her/his following comments that H<sub>2</sub>O profile retrievals are very challenging. This is absolutely true and therefore it is important to investigate if the complex retrieval developments made and published by us in a variety of papers are also valid and useful for remote sensing in the near infrared and when using spectra of lower resolution.

The paper addresses an important current TCCON research issue: developing TCCON profile retrievals. For this purpose there exists a dedicated TCCON profile retrieval working group which is co-led by the authors. Retrieving profiles instead of scaling climatologic profiles – as has been done so far by the standard TCCON retrieval algorithm – should theoretically have the additional advantage of improving the retrieved column amounts. Applying the “high resolution NDACC spectra” trace gas profiles are produced since many years by the ground-based FTIR technique, but profile retrievals applying lower resolution ground-based solar absorption spectra have so far not been presented. In contrast to the claims of the referee, this is not seen as a straightforward issue by the TCCON community. Profile retrievals will be especially important for TCCON's CH<sub>4</sub>, N<sub>2</sub>O, and CO products. However, on a regular basis there are no profile reference measurements for these trace gases available. The situation is different for H<sub>2</sub>O. It is measured at WMO meteorological observatories on a daily basis (e.g. by the Vaisala meteorological radiosondes). Only H<sub>2</sub>O offers the possibility to validate profiles retrieved from TCCON spectra in an extensive

manner. Our study takes H<sub>2</sub>O as an example and documents for the first time that tropospheric profiles (with two independent tropospheric layers) can be retrieved from TCCON measurements and that the quality is very satisfactory. When revising the paper we will make clear (already in the introduction) that the TCCON community is currently working on profile retrievals and that our paper is an important contribution to these efforts.

Another important finding of our paper is that the TCCON spectral resolution is a good compromise for investigating small scale free tropospheric water vapour processes. We show that within TCCON one can measure middle/upper tropospheric water vapour with a unique high measurement frequency (one measurement every few minutes; NDACC high resolution measurements need more time). Such temporarily highly resolved data can be useful for a better parameterization of small scale processes (e.g. turbulent mixing: high frequency measurements would allow calculating probability distribution functions of water vapor for different kinds of meteorological conditions and cloud situations and improve their parameterization). The insufficient description of such small scale processes is a major source of uncertainty when modeling upper tropospheric humidity. Understanding upper tropospheric humidity is however, decisive for understanding and predicting the atmospheric water vapour feedback effect.

We do not see how all these aspects could be merged into our other paper that is currently revised for AMT (Figs. 1, 3, 4, 6, 7 do not fit into our other AMT paper). This other paper is already very comprehensive. It applies ground-based high resolution spectra measured by JPL's MklV spectrometer (a research instrument developed mainly for balloon campaigns) during a special water vapour measurement campaign on Table Mountain Facility, California (the MOHAVE 2009 campaign). It documents the consistency of water vapour and water vapour isotopologue ratio profiles applying highly-resolved ground-based solar absorption spectra and water vapour lines from different spectral infrared regions. The here discussed paper applies lower resolution spectra measured in the near infrared by a commercial Bruker IFS 120/5 HR (the commonly applied TCCON instrument) at the Izaña Observatory, Tenerife Island, Spain, and documents the possibility of TCCON for measuring tropospheric water vapour profiles with a unique high measurement frequency.

#### FURTHER COMMENTS:

The authors do not mention if they completely abide the TCCON regulations or if there are some deviations. E.g.: in publication (1) absolute calibrated spectra were used. Is this also the case in this publication?

We measure according to TCCON regulations (spectral range, spectral resolution) and perform an absolute calibration of the spectra. We will put the absolute units in Figure 2.

The authors mention that the speed dependent Voigt line shape is used for the forward modeling of the spectra. The authors should mention where the additional parameters for this line shape come from. Have they been published? If not they should be noted in this publication.

Yes, this is described in a JQSRT paper, which is cited in the manuscript as "submitted to JQSRT". In the meanwhile it is in press: doi:10.1016/j.jqsrt.2010.09.008.

What are the assumptions on the apriori knowledge, i.e. the apriori profile and the Sa matrix?

Sa matrix and climatologic mean profile are calculated from daily Vaisala RS92 measurements on Tenerife between 2005 and 2009.

The article completely misses any error discussion on the profiles. It is not clear how the authors arrive at the error figures which are given in figure 6 and 7. What about systematic influences of wrong temperature profiles, wrong spectroscopy and so on.

Errors in Figure 6 and 7 are the errors due to noise in the measurement (if you are common with the Rodgers analytic calculation it is  $G_y \cdot \epsilon_{y}$ ).

We will add a plot showing error simulations and a table documenting the assumed error sources.

Why do the authors choose the micro-windows as given in the publication, why not others. Since this is a critical issue, a more thorough investigation of the choice of the microseconds would be certainly beneficial to the TCCON community. Are the AVK dependent on the water vapor content of the atmosphere and if so, how strong.

For these microwindows we showed in the publication (3) that the retrieved profiles are consistent with the profiles retrieved in the mid infrared. This is important and ensures that the profiles retrieved in the different spectral regions (by NDACC and TCCON instruments) can be combined to a consistent data set.

Furthermore, we estimated the strength of the speed dependence for the lines in these microwindows (see JQSRT, doi:10.1016/j.jqsrt.2010.09.008, in press). Applying a speed dependent line shape model is important for ground-based water vapour profile remote sensing.

Are the sondes smoothed by the typical AVK or are those AVK individually calculated for the profiles which are compared to the sondes?

We smooth it with the individual averaging kernels

The authors mention the strong variability of the H<sub>2</sub>O content of the atmosphere (15% in 3 hours) but use sondes which are started 1 h apart from the measurement. Even in 15 min the variability is larger in the water vapor profile than the assumed noise on the measurement. Could the authors please comment on this.

Yes of course, there is a high variability in tropospheric H<sub>2</sub>O. This means that the scatter that we see – when comparing to the sondes – is partly due to this variability, i.e. sonde and ground-based FTIR system detect a different air mass. The scatter observed between the sonde and the ground-based FTIR data is an upper limit of the combined precision of both techniques.

The large gradient and the large range of the water vapor content in the atmosphere are always a challenge for methods measuring water vapor (2). How does the described method cope with this issues?

In deed, ground-based water vapour profile remote sensing is a great challenge. It is important to perform a retrieval on a log-scale and to perform a simultaneous temperature profile retrieval (publication (1)). Lines of different line strength help to achieve good sensitivity for high and low water vapour contents. Furthermore, speed-dependent Voigt line-shape is important.

How is the correlation to a time series of sonde measurements? A few matching profiles are certainly not enough to support the claims made by the authors.

In Tenerife Vaisala sondes are launched at 11:15 and 23:15 UT. Since 2007 we have recorded near infrared spectra (in addition to the mid-infrared measurements that already started in 1999). At Izaña we have one instrument for measuring spectra in different regions: in the mid-infrared “NDACC regions” and the near infrared “TCCON region”. Our

measurement routine was set up as follows: between 10 UT and 13:30 UT we measured in the mid-infrared and around local noon (14 UT) we measured in the near infrared. Therefore, we have only very few coincidences between radiosonde and gb FTIR near infrared measurements.

On several days between April and June 2010 we made extensive near infrared measurement campaigns in order to investigate the variability of water vapour on different time scales (see Figure 6 and 7 of the paper). In that period we had five optimal coincidences between radiosonde and gb FTIR near infrared measurements. These are shown in Figure 5. These five days cover a wide range of different water vapour profiles (variability of more than 100% for different altitudes). We think that these five days are well representative for the high tropospheric water vapour variability.